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To whom it may concern:

This is the final report on NASA grant NAGW-3838, "What Drives the Outflows in Broad Absorption Line QSOs?" (PI: Mitchell C. Begelman, The Regents of the University of Colorado, Campus Box 19, Boulder, CO 80309-0019), covering the period 4/1/94-9/30/97.

This grant has provided partial support for one graduate student (N. Arav) and two postdoctoral researchers (N. Arav, M. de Kool). We have made progress on 3 areas related to the propulsion and confinement of gas responsible for broad absorption troughs in QSOs:

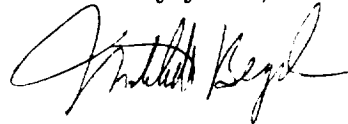
- Radiative Acceleration in BALQSOs: Arav, Begelman, and Z. Li (then a graduate student working with Begelman) adapted the standard theory for radiatively driven O-star winds (Castor, Abbott & Klein 1975) to the very different conditions thought to exist in the outflows responsible for broad absorption lines (BALs) in quasars. Instead of the $\sim 10^4$ lines responsible for accelerating O-star winds, at most a few dozen strong resonance lines (and probably just a handful) contribute to the acceleration of quasar winds. The radiation force is also a much more steeply decreasing function of column density in the latter case. We showed that radiative acceleration was consistent with the observed ionization states and profiles of the BALs, and developed quantitative models for BALQSO spectra.
- The "Ghost" of Lyman α : While the existence of the BALs implies the absorption of significant photon momentum by the outflowing gas, proof had been lacking that UV radiation pressure *dominates* the acceleration process. Arav and Begelman, however, have shown that the characteristic "double-trough" structure often observed in C IV

BAL profiles (first noted by Weymann et al. 1991) is a strong indicator that the gas is accelerated by the radiation force due to only a few of the strongest UV resonance lines. In effect, the double trough structure is a "ghost" of the N V 1240 Å/Ly α 1216 Å emission line complex. We infer that resonance scattering of N V alone must provide about 10-20% of the total radiation force in those objects which show the double trough, and predict that the continua of these objects will be found to drop sharply shortward of 1200 Å.

- *Magnetic Confinement of Absorbing Gas*: The gas responsible for QSO broad absorption lines must be confined to a small fraction of the total volume, in order to maintain the correct ionization state. De Kool and Begelman developed a hybrid model in which absorbing cloudlets are accelerated by radiation pressure, along combed-out magnetic field lines. The radiation force confines the clouds parallel to the field lines, while magnetic stresses provide lateral confinement and prevent the clouds from spreading sideways. In addition to explaining the covering factor and inferred geometry of the BAL outflows, our model provides a natural explanation for the small size of the individual absorbing cloudlets.

A list of publications resulting from this grant is attached.

Sincerely yours,

A handwritten signature in black ink, appearing to read 'Mitchell C. Begelman', with a stylized, flowing script.

Mitchell C. Begelman
Principal Investigator

PUBLICATIONS SUPPORTED BY NASA GRANT NAGW-3838

What Drives the Outflows in Broad Absorption Line QSOs?

Principal Investigator: Mitchell C. Begelman

Final Report: December 1, 1997

1. *Papers in Refereed Journals (published, in press and submitted)*

- Arav, N. 1996, "Ghost of Ly α as Evidence for Radiative Acceleration in Quasars," *ApJ*, 465, 617-630.
- Arav, N., and Li, Z. 1994, "The Role of Radiative Acceleration in Outflows from Broad Absorption Line QSOs. I. Comparison with O Star Winds," *ApJ*, 427, 700-707.
- Arav, N., Li, Z., and Begelman, M. C. 1994, "The Role of Radiative Acceleration in Outflows from Broad Absorption Line QSOs. II. Wind Models," *ApJ*, 432, 62-74.
- Arav, N., and Begelman, M. C. 1994, "Modeling the Double-Trough Structure Observed in Broad Absorption Line QSOs Using Radiative Acceleration," *ApJ*, 434, 479-483.
- Arav, N., Korista, K. T., Barlow, T. A., and Begelman, M. C. 1995, "Radiative Acceleration of Gas in Quasars," *Nature*, 376, 576-578.
- De Kool, M., and Begelman, M. C. 1995, "Radiation Pressure Driven Magnetic Disk Winds in Broad Absorption Line QSOs," *ApJ*, 455, 448-455.

2. *Invited Review Articles*

- Arav, N. 1997, "A Signature of Radiative Acceleration in BAL QSOs," in *Mass Ejection from Active Galactic Nuclei*, PASP Conf. Series 128, N. Arav, I. Shlosman, and R. J. Weymann, eds. (San Francisco: Astron. Soc. Pacific), 264-269.
- De Kool, M. 1997, "An Overview of Dynamical Models for Outflows in BAL QSOs and Seyferts," in *Mass Ejection from Active Galactic Nuclei*, PASP Conf. Series 128, N. Arav, I. Shlosman, and R. J. Weymann, eds. (San Francisco: Astron. Soc. Pacific), 233-245.

3. *Ph.D. Thesis*

- Arav, N. 1994, "Studies in Radiation Hydrodynamics," Ph.D. Thesis, University of Colorado, Boulder.